Characterization of Extrasolar Planets using SOFIA

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First part of this talk:

the landscape of extrasolar planets
why focus on transiting planets
some history, Spitzer results

Posters by Angerhausen & Krabbe
+ HIPO poster by Dunham et al.

Then:

- Hot Jupiters: a problem in atmospheric structure
  also hot super-Earths
  What observations we need to make progress
  What SOFIA can currently do
  and comments on optimized instruments
Summary of the known exoplanets

Deming & Seager
review in Nature
462, 301 (2009)

Also, Seager & Deming
ARAA (2010), astro-ph/1005.4037

SOFIA in follow-up,
not discovery mode

Timing
Radial Velocity
Transit
Microlensing
Direct Imaging
Astrometry
Exploit *transits* to characterize exoplanet atmospheres...

Transits require photometric stability

But tolerate poor image quality

few $x 10^{-3}$ FLITECAM & FORCAST(?)

few $x 10^{-4}$ HIPO + FLITECAM
Methane and water vapor in transmission (HD189733b)

Arguably, SOFIA continuous viewing is a good tradeoff for some telluric water...

Charbonneau, Brown, Collier-Cameron, Deming, Richardson, Wiedemann, and others struggled towards ground-based detection
"First Light"
Thermal Emission

Spitzer enables direct detection of IR light from the planets

eclipse depth $\sim (R_p/R_{\text{star}})^2(T_p/T_{\text{star}})$
yields $T \sim 1100K$

Six Spitzer photometric bands can give a low resolution spectrum of the planet
Eclipse of HD 189733B

eclipse depth $\sim (R_p/R_{\text{star}})^2(T_p/T_{\text{star}})$

**Dominant term**

$T_p \sim T_{\text{star}} \Delta^{0.5}$

*lower main-sequence stars allow high S/N planet detection*

HD 189733b (K3V)

32σ detection at 16 μm

An Exoplanet Spectrum (R ~ 100)

HD189733b
(At Secondary Eclipse)

Grillmair et al. (2008)
Deming et al. (2006)
Charbonneau et al. (2008)

$P_n = 0.1, \kappa_e = 0.0 \text{ cm}^2/\text{g}$
$P_a = 0.3, \kappa_e = 0.0 \text{ cm}^2/\text{g}$

Many other planets show inverted atmospheric structure

Grillmair et al. 2008
Nature 456, 757
The MEarth Project
Charbonneau et al.

- Using 8 X 16-inch telescopes to survey the 2000 nearest M-dwarfs for rocky planets in their habitable zones
- Converted an existing abandoned building on Mt Hopkins, AZ
- Fully operational; southern version planned
- These planets will be amenable to spectroscopic follow-up to search for atmospheric biomarkers
The First MEarth Super-Earth

Nearby, hotter super-Earths to come
TrEs-4 — apparently an inverted atmosphere

But there are degeneracies...
...Warm Spitzer has only 2 bands

The very hot Jupiters' atmospheres perturbed by strong irradiation? losing mass by tidal stripping?

CoRoT-2

High S/N for WASP-12 at filter resolution

Instrument considerations:
- maximize the spectral range
- $R \sim 100$ is OK
- maximize stability
- consider $\lambda$-dithering

hot super-Earths?
Conclusions and comments

- SOFIA with current instruments can make significant progress on the science of transiting exoplanets
  - Mass loss and atmospheric structure of very hot Jupiters
  - Complementary to Warm Spitzer
  - Possibly can characterize hot M-dwarf super-Earths

- Instrument enhancements should concentrate on stable 1-5 μm spectroscopy, maximizing the spectral range at relatively low spectral resolution